BERLIN TECHNICAL UNIVERSITY
SPECIAL BRANCH FOR RESEARCH IN MAGNETOHYDRODYNAMICS
(SFB-MHD)

TECHNISCHE UNIVERSITAT BERLIN
SONDERFORSCHUNGSBEREICH MAGNETOHYDRODYNAMIK

BY

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BERLIN TECHNICAL UNIVERSITY

Special Branch for Research in Magnetohydrodynamics

(SFB-MHD)

Dr. L. Prem

Atomics International

North American Rockwell

P. O. Box 309

Canoga Park, California 91304 USA

1000 Berlin, 9 October 1970

Dear Dr. Prem,

I am very sorry that I can only now send you our trip report. My excuse is that the writing took so long (and the report has become voluminous), we had difficult days, and my visit in Moscow came in the meantime. I have sent our report and your summary, for which I thank you, to our Ministry. Thus it may be hoped that our meeting was the first in a long series.

We have read your report, and it contains all the important points. You will see that we have stressed some additional interesting information.

There is much to report from Moscow. In every case liquid metal MHD was intensively pursued. Your ideas on the later application of our system coincide somewhat with those of our Russian colleagues, although the nuclear side is more in the foreground.

It is to be hoped that you and your group are not troubled by reductions, but are making progress. I remain with many greetings and best wishes for the work,

Yours,

(R. Radebold)

SFB-MHD Berlin, 25 September 1970

Cooperation (USA - Federal Republic of Germany) in the area of magnetohydrodynamic energy conversion:

Subpanel on liquid metal MHD energy conversion.

Subject: Report on the trip of the working group for high temperature liquid metal and material technology to Los Angeles from 13 June, 1970 to 18 June, 1970.

This report consists of three parts:

Part 1 concerns information about the meeting, a summary of its results, and some conclusions for the German working group.

Part 2 contains the results of this meeting, listed according to concrete problems which should be solved jointly.

Part 3 contains additional information of interest for this work area, as well as new literature reports.

Part 1 of the trip report:

1.1 Basis of the Trip

In the preliminary draft of the German-American agreement on cooperation in MHD research, sub-panels were proposed for various areas. As a first step in cooperation, these sub-panels, through discussions of the work, were to work out the status of technology and the research results necessary to realize the goals set up. One of these working groups was formed for "High Temperature Liquid Metal and Material Technology".

1.2 Members of the working group

The following were named members of the working group:

R. Schiltz	Argonne National Laboratory (ANL)
D. Cerini	Jet Propulsion Laboratory (JPL)
C. Baroczy	Atomics International (AI)
L. Prem	Atomics International (AI)
R. Radebold	AEG
K. Wagner	DFVLR
H. P. Schwefel	AEG

1.3 Participants in the meetings

The participants in the meetings were the persons designated in section 1.2, with the exceptions of Dr. R. Schlitz, who was replaced by Dr. F. Smith of ANL, and of Mr. Schwefel, who was replaced by Mr. Stubing.

1.4 Inspections

Inspections of the following establishments were included in the meetings:

1.4.1 Liquid Metal Engineering Center of AEG in Santa Susana.

1.4.2 Liquid metal - MHD - test stands (K and Na) of Atomics International in Santa Susana.

1.4.3 Production of Na-H_2O heat exchangers for SBR at Atomics International in Canoga Park

1.4.4 Liquid metal MHD test stands (NaK, Li, Cs) of the Jet Propulsion Laboratory in Pasadena.

1.4.5 MHD test installations for Ar-NaK streams in the Argonne National Laboratory (by Dr. Radebold only).

1.5 Host

The meeting was organized by Dr. L. Prem and took place at the Atomics International company in Canoga Park. The meeting was distinguished by marked hospitality.

1.6 Summary of the results

The area of liquid metal technology can generally be divided into three regions, depending on the materials used and the degree of difficulty.

Region 1 reaches from about 500°C to a maximum of 650°C. Considered technically, it includes the equipment of present-day sodium-cooled fast breeder reactors.

Region 2 runs from about 750°C to a maximum of 1000°C. It includes one-component liquid metal MHD energy conversion systems. Its upper limit is essentially set by the construction material Haynes 25 (2.4967), which combines scale-free resistance to alkali metals with adequate creep resistance with time.

Region 3 extends above 1000°C and comprises two-component liquid metal MHD systems for extra-terrestrial energy conversion. It can only be realized by use of refractory metals in vacuum.

The host placed great value on convincingly demonstrating the present state of technology -- i. e., Region 1. This was provided by inspections 1.4.1 and 1.4.3, and by numerous lectures by experts from the fast breeder reactor group at AI. In conclusion, one can say that large technological establishments have been built and controlled.

Region 2 was then considered on this basis. Inspections 1.4.2 and 1.4.5 showed the state of technology, which is, however, in no way comparable with that of Region 1. The task of the working group in the frame of the planned cooperation, aside from MHD problems proper, is to transfer the technological knowledge which can be considered as correct up to 650°C, up to the temperature region as high as 1000°C. Part 2 of this report indicates the problems to be solved there.

Vaporization experiments with alkali metals at 850°C as well as nozzle experiments show that beginnings have been made for Region 2 technology in the USA. It need not be emphasized that the USA has a strong advantage because of many preliminary works. On the other hand, there is surprisingly little experience with the construction material Haynes 25. Here, thanks to the early decision of the BMBW to have the large MHD test stand built of Haynes 25, we have a small advantage. We were assured that our experience and in particular our construction capabilities are expected to allow construction of a larger test stand (JPL).

Work in the MHD area proper is stagnating at AI and AML, while the working group of Dr. Elliott at JPL can work without restrictions toward the goal of a 300 kW power supply for space flight. We did not recognize any technological developments of noticeable extent in Region 2. However, at AI, test stands for MHD systems have been operated for more than four hours at 870°C. Here the state of technology may be comparable with ours. The general problem is in purification methods and especially in development of instrumentation so dependable that equipment can be built in quantity and installed without its having to be considered the subject of research. The same applies for the systems proper and their components, until interest can be concentrated exclusively on the physical processes in the systems, and the systems themselves present no more significant problems.

The very great difficulties of temperature region 3 were apparent from the inspection 1.4.4. Consideration was unanimously deferred by the working group.

1.7 Consequences for the special branch for MHD research.

Work on instrumentation in the temperature region 2 (up to 1000 °C) must be completed with high priority. It is absolutely necessary to continue intensively the development of SCHOELLER-BLECKMANN and BOHLER on the working of Haynes 25 into cold-rolled tubes. Corrosion investigations no longer seem important, since GE in Evendale has operated a closed cycle for more than 44,000 hours at 1010°C. Temperature embrittlement remains problematical.

At present, the major point of the work at the special branch for MHD research is not on investigation of the long-term aspects of installations. However, there are aspects of the tasks of the special research branch,on one hand, and of the research themes presented in the appendix on the other hand, which have as yet not been adequately considered.

a) Even for the operation of relatively "short-lived" test stands, it will be necessary to raise the purity requirements for alkali metalshigher than has been usual in special research branch projects. Here, therefore, work is necessary as well as desirable in the framework of cooperation.

b) The special research branch's planned operation of test stations at high temperatures makes it appear desirable to consider "error detection programs" for the operation of these stations. By this it is meant that when defects appear they are not only eliminated, but also analyzed. For this purpose the investigation of test stands and manufacturing and testing results with respect to this group of questions is necessary. This could also be a contribution toward planned cooperation.

c) The working conditions must be decisively improved by construction of a "clean room". Otherwise it will be impossible to fulfill the requirements for purity, as has been done so far, without very great difficulties (if at all).

d) The planned operation at high temperatures in itself makes it possible to undertake directed technological investigations. However, appropriate results will not appear without directed questioning and suitable modification of the test establishments. Valuable contributions might be provided through extension of the special branch's research program, within flexible limits, directly into the area of special design from thin sheets (instead of the previously common power plant designs). This has not yet been closely investigated. Such study would also be desirable within a cooperative framework.

Part 2 of the trip report

Summary of the problems which should be solved jointly.

A. Working media

Calculation and/or experimental determination of the physical and thermal properties of

1. Alkali metals other than potassium and sodium [1]
2. Two-component mixtures, to the extent that the necessary data are not at hand.

B. Materials technology

The investigations should include two temperature ranges, namely the region of about (850°C to 950°C) and temperatures above this (850°C to 950°C).

1) for the thermodynamic engine
   a) information on erosion
   b) construction possibilities (including welding techniques) for superalloys (e. g., Haynes 25) to the extent that they are considered for the thermodynamic engine.
   b) investigations on duplex materials (preparation and properties)

Footnote 1 is on page 26

2) for the heat source

   a) summary of data and investigation of materials for

      (i) electrically-heated heat sources

      (ii) heat sources fired with fossil fuels

      (iii) nuclear heat sources

   b) after the choice of a particular heat source: summary of data and investigation of materials for construction

   c) study of life-time

3) for connecting pipelines and other structures of the installations

   a) missing data on long-term behavior

   b) mutual influence of different materials in the system (material transport, electrolysis, etc.)

   c) assembly procedures at the construction site

   d) investigation of components (valves, connections, pumps)

   For all these points: further questioning at the request of other sub-panels.

C. Corrosion

1. Summarization of special corrosion effects in MHD systems

   a) establishment of the corrosion mechanisms in MHD systems

   b) determination of allowable corrosion

c) fouling (accumulation) effects and mass transport

2. Summarization of technical data now available for research programs.

   a) determination of permissible corrosion

   b) fouling (accumulation) and mass transport effects

   c) hot gas effects

3. Summary of necessary work

   a) high temperature data

   b) data for high flow velocities

   c) hot gas effects

   d) effect of magnetic fields and higher flows

   e) effect with duplex materials (electrolysis)

   f) determination of the type and presence of possible defects

   g) defects induced by radioactive radiation

D. Purification of the working media

   a) source of impurities

      (i) at high temperatures (750°C to 1000°C)

      (ii) of chlorides in particular

   b) their effect on the system

      (i) in operation at high temperatures

      (ii) of chlorides in particular

   c) purification methods

      (i) in operation at high temperatures

      (ii) with particular respect to chlorides

d) specification of the degree of purity necessary for a typical MHD working medium

   (i) quantitative statements for selected systems

e) preparation of detailed operating instructions for purification.

E. Safety and sources of danger

a) drainage containers, steam generators
   In this connection, see the SBR program and other sodium systems

b) thermodynamic engines
   Definition and description of a typical system

c) heat sources

   (i) with fossil fuels

      a) leakage from the system into the combustion chamber

      b) leakage from the combustion chamber into the system

      c) fire-fighting

   (ii) nuclear heat sources
   Information on the SBR projects.

F. Instrumentation

1. temperature measurement

   condition of safety and redundance of measuring points

   a) experimental phase

   b) demonstration phase

2. flux measurement

a)	single-phase	development of existing methods for temperatures of 850°C and above
b)	two-phase	utilization of known research and development work for possible applications
c)	multi-component streams	no suitable methods are known

3. pressure measurement

   note as for 1.

4. detection of leaks

   a) for steam generators, pipes, and valves, see SBR program

   b) thermodynamic engine, generator, nozzles: methods must be provided.

   c) heat sources: methods and suitable equipment must be developed.

5. measurement of the state of filling

   a) test and choice of existing equipment for temperatures of 850°C and higher

   b) development of other methods (e. g., acoustic, gamma-ray, and the like)

6. measurement of the degree of purity of the working medium

    a) test of existing methods for use in typical MHD systems

    b) development of instruments for measuring the degrees of purity which will be determined in D, d).

G. Heat sources

  a) firing with fossil fuels

    (i) critical review is available

    (ii) firing for typical MHD application, as well as effects of stratification and heat conduction problems must be investigated.

  b) nuclear heat sources

    collection and critical testing of advances in the area of high temperature reactor technology

H. Vaporization and stability of the flow

  1) spraying (nozzles)

  2) boiling in flow through tubes

  3) boiling in a pool

  4) experimental and theoretical studies on

    a) stable boiling

    b) condensation

    c) condensation surges

5) boiling, condensation/separation of two-component alkali metal systems

J. Characterization of the temporal course and the priority of the work.

Priority	Work as soon as possible	Work in the more distant future
	boiling and stability of the flow (H)	working media (A)
highest	construction material technology (B) + purification of working media (D)	heat sources (G) + safety and sources of danger (E)
	instrumentation (F)	construction material technology (B) + corrosion (C) + purification of working media (D)
	corrosion (C) + heat sources (G)	instrumentation (F)
	safety and sources of danger (E)	also: general construction process
lowest	working media (A)	

Part 3 of the trip report

1. Some special technical information and statements on the literature

   a) purification of the alkali metals

      (i) filtration is said to be unnecessary, as long as the purity requirements are met for containers, pipelines, and armatures, and as far as the circuit through the installation and its components, and the alkali metal itself correspond to the purity requirements.
      It can be said from our own observation (inspections at AI in Canoga Park and at the AI and CEC installations in the mountains, as well as from the JPL inspection) that the purity requirements are certainly fulfilled in these installations, and that they differ from our installations and areas, to our definite discredit.

      (ii) for the purity needed with respect to oxygen concentration (between 10 and 30 ppm) in the SBR projects, they employ, as we do, cold traps in by-pass streams (10% of the total circulating mass) operating during the total running time.
      The results are good.

(iii) in special test installations (e. g., corrosion investigations) hot traps are used for smaller oxygen content. Zirconium or an alloy of zirconium and titanium is used as a scavenger metal. The latter has an even higher affinity for oxygen than does zirconium alone. Both form an insoluble oxide film.

Tantalum is <u>not</u> used, because the tantalum oxide dissolves and/or is stripped off and carried out. <u>This aspect is also important for the operation of TA installations</u>!

For the design of hot traps (which should be planned with a safety factor of about S = 10) appropriate documents, along with /1_7 and /‾2_7 are available.

(iv) purification of the alkali metals from carbon. A hot trap is used, with 304 SS as scavenger. The only condition for SBR is that the temperature of the hot trap must be higher than all the other parts of the circuit. It is realizable there.

(v) purification of potassium with respect to oxygen.

Oxygen saturation values for potassium are quite unreliable. Exact values can be waived temporarily, since the purification mechanism

works as follows:
At any temperature, sodium has a stronger affinity for oxygen than does potassium. As long as there is enough sodium in the potassium, sodium oxide (Na_2O) precipitates in a cold trap. Since there is no longer equilibrium, the oxygen bound to potassium is not transferred to the sodium, and so on. Thus the potassium can be purified adequately in spite of the higher oxygen solubility in it, even at lower temperatures.

The requirements for sodium content in potassium are:

$$30 \text{ ppm} < Na < 5000 \text{ ppm}$$

It must be remembered that during the operation of the cold trap, the sodium concentration decreases along with the oxygen concentration.

(vi) Mr. Wagner has some documents with respect to chemical affinities.
Further inquiries should be sent to Dr. McKisson, directly or via Dr. Radebold at AI (address below).

b) Prices of potassium in America (MSA)

Specifications: $O_2 < 500$ ppm
$C < 100$ ppm
$Na < 2\%$

200 lb: $2.50/lb

3000 lb: $1.93/lb

O_2 $<$ 50 ppm

C $<$ 50 ppm

Na ca. 5000 ppm

about $10/lb.

c) solubility of gases

ANL 7561; ANL 7325

ANL 6900; ANL 7457

In spite of the slight solubility of nitrogen, there is a great effect on corrosion at the sodium-nitrogen-container wall interface. For this reason, nitrogen is to be avoided as a protective gas (especially at high temperatures).

d) measurement of impurity

In operating systems, the "plugging meter", as before.

In test installations, either analysis (distillation method) or

"Electrochemical O_2 -Meter

United Nuclear Corporation

White Plains

USA

measurement of carbon content:

introduction of a probe of 304 SS, and finally analysis.

e) corrosion

Particular statements on corrosion of Haynes 25 were not available. Information on other alloys and special literature on corrosion (as well as other questions) at: "Liquid Metals Information Center", address below.

Some special literature on Tantalum corrosion: [3]. Further: [4]; [5]; [6]

f) safety and sources of danger

(i) On design of installations for systematic failure analysis: see [7].

For further information, via Dr. Radebold or directly to F. A. Smith

Reactor Engineering Division

Argonne National Laboratory

Argonne, Illinois

USA

(ii) Security precautions at the installations inspected:

Adequate drainage containers in reinforced and isolated excavations. Installations either in unpopulated areas (mountains or deserts near Los Angeles) or in areas where the installations are built so that they can be flooded with nitrogen.

(iii) Reactions of sodium or potassium with air at temperatures over the normal boiling point have not been investigated!

g) boiling and spraying

(i) Mr. Prem and coworkers report that they have attained "stable boiling" with potassium in a circulating heater with heating by radiation at about 800°C, independent of changes in working conditions and arbitrarily reproducible. In this respect, see [8].

(ii) NASA has carried out numerous investigations on the boiling up (sputtering) of alkali metals on passage through nozzles. On this, see [9].

h) for two-component operations, see [10] .

j) for two-phase acceleration, see [11] .

k) circulation concepts and systems

For considerations, see [12]; [13]; [14]

2. Some important addresses and establishments

a) Mr. L. Prem

Atomics International Division

Canoga Park

California

USA

b) Liquid Metals Information Center
P. O. Box 1449, Canoga Park
California 91304
USA

c) ANL: see point 1(vi)

d) for ordering literature, see the bibliography, /‾9_7 .

3. Literature

/‾1_7 * J. P. Pemsler
Studies on the Oxygen Gradients in Oxidizing Metals. I. Zirconium
J. Electrochem. Soc., Vol. 111, No. 4, April, 1964.

/‾2_7 * R. J. Hussey; W. W. Smeltzer
The Mechanism of Oxidation of Zirconium in the Temperature Range 400°C to 850°C
J. Electrochem. Soc., Vol. 111, No. 11, November, 1964.

/‾3_7 Klueh
"Corrosion by Liquid Metals"
AIME Symposium on Liquid Metals
Philadelphia, Pa.; Oct. 13-15, 1969; USA.

/‾4_7 * L. G. Hays
Corrosion of Nb - 1% Zr alloy and Yttria by Lithium at high flow velocities
(JPL) NASA - Tech. Rep. 32-1233, 1967.

/‾5_7 * L. G. Hays; D. O'Connor
A 2000°F Lithium Erosion and Component

Performance Experiment
(JPL) NASA - Tech. Rep. 32-1150, 1967

[6] * L. G. Hays
Surface Damage from High Velocity Flow of
Lithium
in preparation

[7] * F. A. Smith
Physico-chemical Mechanics of Metals in
Nuclear Reactors
Int. J. Nondestructive Testing
Vol. 1, 1969.

[8] L. Prem Baroczy
"Stabilized Boiling"
CEP Symp. Ser. Vol. 64, No. 82, 1968.

[9] * O. A. Gutierrez, D. B. Fenn
Experimental cavitation and flashing of
potassium flowing adiabatically through a
venturi sized as a boiler inlet.
NASA TND - 5738
Can be ordered from:
Clearinghouse for Federal Scientific and
Technical Information
Springfield, Virginia 22151
USA

[10] * Gerald M. Kikin et al
Lithium - Boiling Potassium Test Loop
(JPL) NASA Tech. Rep. 32-1083 (1966).

[11] * Robert B. Eddington
Investigation of Supersonic Shock Phenomena in a Two-Phase (Liquid-Gas) Tunnel
(JPL) NASA Tech. Rep. 32-1096 (1967)

[12] * D. G. Elliott
Cycle Analysis Results for Cs-Li MHD Converter
in preparation, 1970.

[13] * L. L. Prem; W. E. Parkins
Outlook for binary power plants using liquid-metal MHD
IEEE Spectrum, May, 1970.

[14] * D. G. Elliot et al
Investigation of a liquid-metal MHD power system
5th Intersociety Energy Engineering Conference
Las Vegas, Nevada, Sep. 21 - 25, 1970.

* The papers designated are in the library of the Special Research Branch.

FOOTNOTES

German page	English page	
9	10	Since these can be assumed to be adequately known.